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A NOTE ON FENNOSCANDIAN SEISMICITY

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Earthquake Research Institute, University of Tokyo

Abstract

In 1953, BÅTH [1] gave $b = 0.46$ as the coefficient of the magnitude frequency relation $\log N = a + b(8 - M)$ for Fennoscandian earthquakes. This seemed very small compared with the values reported for the other earthquake regions of the world. As the recognition of several seismic sub-zones in Fennoscandia based on epicenter distribution, the magnitude frequency relations for these sub-zones were calculated by the method of least squares from the new data reported by BÅTH 1956 [2]. No significant differences existed between the b-values for the sub-zones. Thus the author calculated b for Fennoscandia as a whole and obtained $b = 0.54$, which again seems to be smaller than the values for the seismic active regions of the world. The difference proved to be statistically significant.

1. Introduction

The magnitude frequency behavior of different earthquake regions has been discussed by many authors ever since GUTENBERG and RICHTER [4] established the formula $\log N = a + b(8 - M)$ for the number of shocks N with magnitude M, a and b being constants. Many seismologists, e.g. SUZUKI [11], RIZNICHENKO [9] have insisted that the values of

the coefficient b are empirically constant, within the limits of statistical variation, for all earthquake regions ever investigated. However, the author cannot understand how they explain the fact that in the continental block movement regions, such as Central Asia, the numbers of shocks of larger magnitude relative to those of smaller magnitude are definitely greater than in the oceanic seismic belts, such as the Mid-Atlantic Ridge, where larger shocks with $M \geq 8$ have never occurred. It has been established by the author [7, 8] that the magnitude frequency behavior of each earthquake region bears a close relation to the tectonic stage of development of that region. Generally speaking, earthquakes are considered to be manifestations of tectonic movements of the earth's crust in each region. The values of b for the oceanic seismic belts seem to be within the range of $1.8 - 1.3$. For the island arcs consisting of smaller islands, the b values become smaller around $1.3 - 1.0$. For the island arcs consisting of larger islands and the arcuate mountains in the circum-Pacific and Alpine belts, the values of b proved to be $1.0 - 0.7$. For the areas subjected to block movements, the b values are $0.7 - 0.6$, regardless of whether the areas lie in the rejuvenated continental block or in the stiffened old orogene in the island arcs. From the above-mentioned facts it can readily be concluded that the tectonically younger stage is represented by the larger value of b and the older stage by the smaller value of b. BÅTH [1] gave $b = 0.46$ for the Fennoscandian earthquakes and this is one of the smallest values of b in the world, like those for a few other regions, such as South America and Australia. It is very tempting to infer that such small values of b correspond to the oldest stage of tectonic development of the earth's crust, extrapolating the relation between b value and tectonic stage of development cited before.

However, the writer considered that it might be necessary to examine these extremely small values of b. As TSUBOI [13] has pointed out, the magnitude frequency relation $\log N = a + b\,(8 - M)$ cannot be valid both for the sub-divisions of an area and for the whole area at the same time, unless the b's are the same in all cases. If the b's for the sub-divisions of the area are not constant, the value of b obtained for the whole area must be fictitious. The present author has therefore examined the original data and investigated the magnitude frequency behavior not only for Fennoscandia as a whole but also for its sub-divisions, in order to confirm that such a small value of b for Fennoscandia is a reliable one.

2. Magnitude frequency of Fennoscandian earthquakes according to the data used by Båth, 1953

BÅTH [1] used the data for the period 1891 — 1930 to obtain the magnitude frequency relation $\log n'' = 2.11 - 0.46\,M$ for the annual number of shocks n'' in Fennoscandia. Although he made no statement on the subject, he seems to have excluded the number of shocks with $M \geq 5.5$ when he arrived at this formula. Re-calculation from the same numerical data by the method of least squares for the different magnitude ranges gives the following results:

(1) $M = 2 - 6$: $\log n'' = (- 2.18 \pm 0.31) + (0.59 \pm 0.09)(8 - M)$

(2) $M = 3 - 6$: $\log n'' = (- 2.43 \pm 0.31) + (0.67 \pm 0.12)(8 - M)$

(3) $M = 2 - 5$: $\log n'' = (- 1.46 \pm 0.13) + (0.44 \pm 0.04)(8 - M)$

3. Seismo-tectonic zoning of Fennoscandia

As BÅTH [1] stated, the epicenter distribution over Fennoscandia may be easily divided into four sub-zones, i.e. (I) Nordlandet, (II) Vestlandet, (III) Oslo-Väner Region and (IV) the Bothnian Region. This is clearly seen in the old seismicity map of SAHLSTRÖM [10], but the epicenter map based on the new catalogue of BÅTH [2] also clearly justifies these divisions, as is seen from Fig. 1.

Considering the tectonic structure of Fennoscandia, the seismic sub-zones cited above correspond very well to the respective tectonic subdivisions provided that we separate the Karelian Region from the Bothnian Region, and this is not so unnatural, as we see, when we examine the epicenter map closely. Thus we adopt the following seismo-tectonic zoning for Fennoscandia, the boundaries between the sub-zones being drawn along the meridians and parallels as shown in Fig. 2, in order to facilitate the use of the magnitude frequency statistics given in BÅTH's catalogue:

(1) Nordlandet   Caledonides
(2) Vestlandet   Caledonides, granitized
(3) Oslo-Väner Region   Rhipheides
(4) Baltic Region   Svecofennides
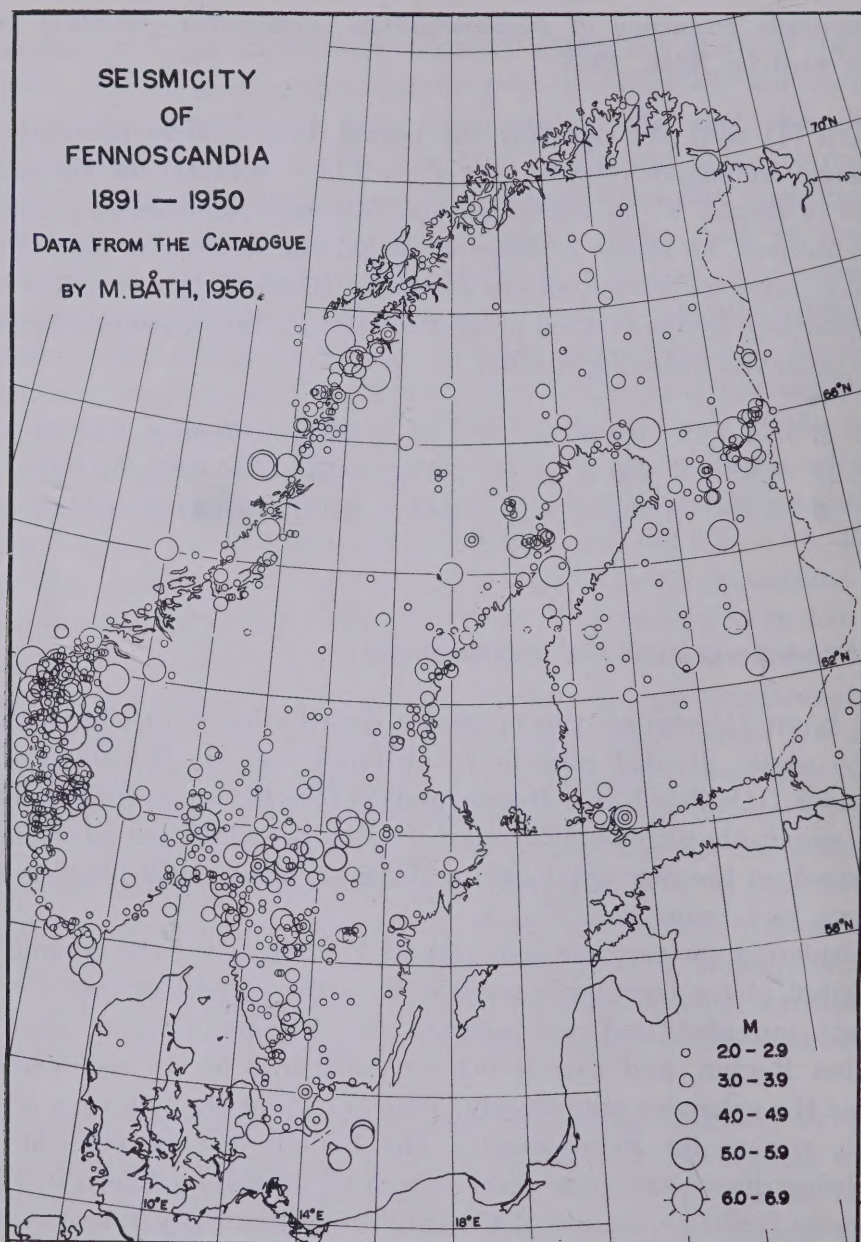(5) Karelian Region   Karelides

Fig. 1. Epicenter map of Fennoscandian earthquakes for the period 1891 — 1950
after the catalogue compiled by BÅTH, 1956.

4. *Seismicity data for the sub-zones of Fennoscandia*

As stated in the previous section, BÅTH [2] compiled an authentic
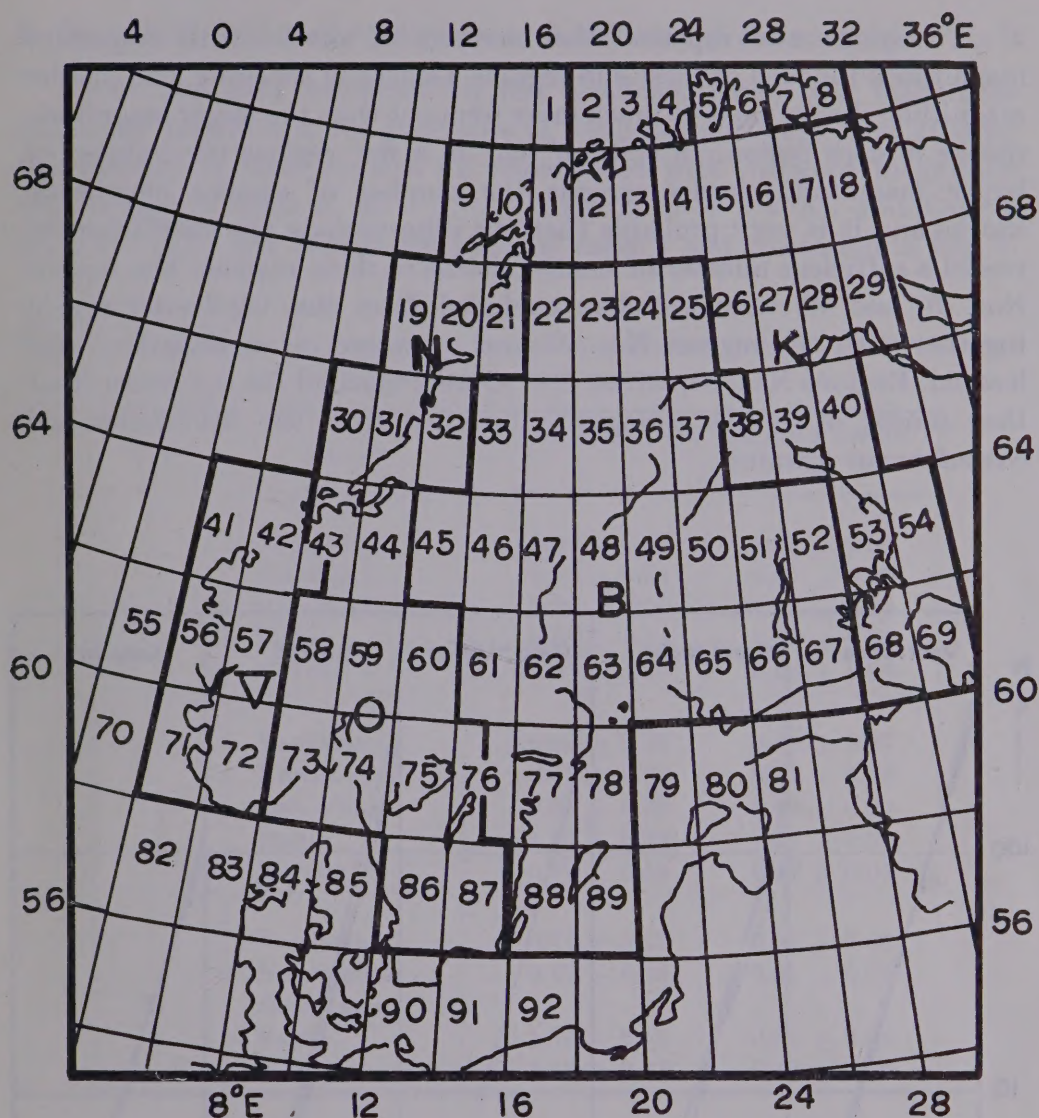catalogue of Fennoscandian earthquakes for the years 1891 — 1950,

Fig. 2. The map showing the division by BÅTH, 1956, comprising 2° lat. × 2° log and the five sub-zones: Nordlandet Region (N), Vestlandet Region (V), Oslo-Väner Region (O), Baltic Region (B), and Karelian Region (K).

and it is one of the most complete records for the seismicity of a non-seismic region of the world. In order to adopt it as basic material for a statistical analysis, the writer examined the data from the viewpoint of magnitude frequency. BÅTH [2] divided the whole of Fennoscandia into

$2° \times 2°$ regions and reported the numbers of shocks with respective magnitudes for each of these sub-regions. Generally speaking, the smaller magnitude shocks must be much more frequent than the larger magnitude shocks in each region. In spite of this, in a few regions the number of larger magnitude shocks exceeds the number of smaller magnitude shocks and it is very probable that the observations are insufficient to record a sufficient number of smaller shocks in these regions. The regions Nos. 70 and 83 were therefore excluded from the Vestlandet region together with the regions Nos. 55 and 82 where no earthquakes were located. Regions Nos. 84, 85, 90, 91, 92 were omitted for the reason that they consist of terrain geologically different from the Oslo-Väner and Svecofennian terrains.
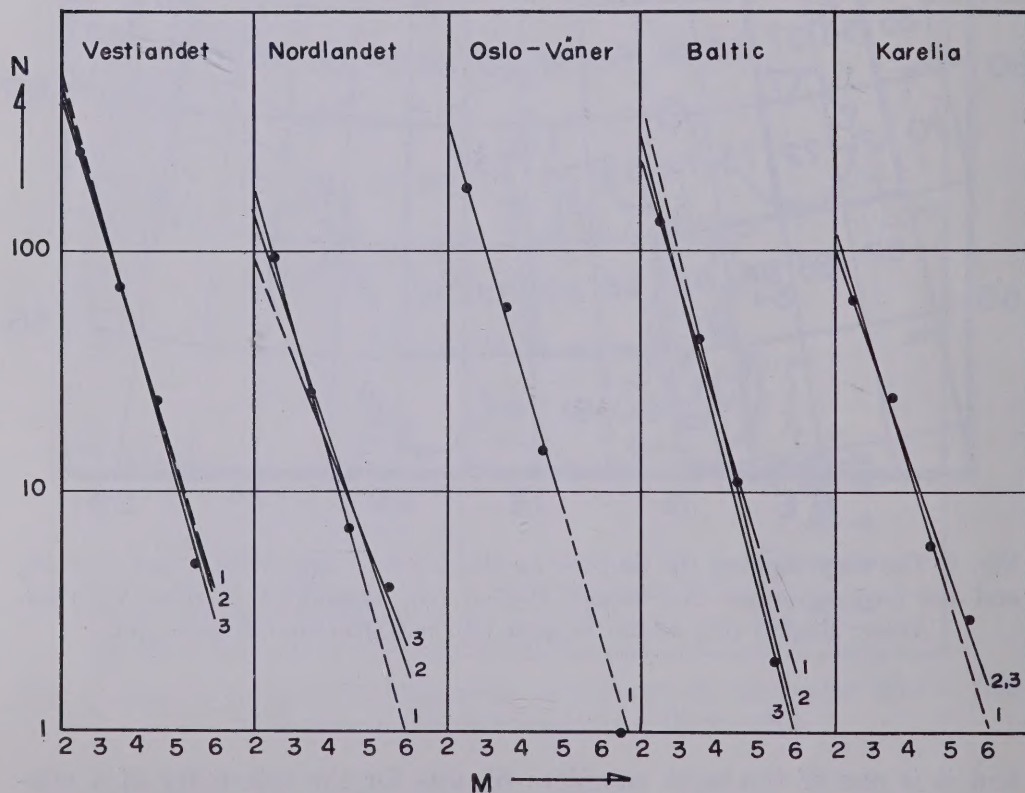

Fig. 3. Magnitude frequency relations for the sub-zones of Fennoscandia.
1 — 3 means the range of magnitude adopted in calculating the straight lines corresponding to cases 1 — 3 in Table 1.

5. *Magnitude frequency relation in each sub-zone of Fennoscandia*

From the data examined in the previous section the magnitude frequency relations in the sub-zones of Fennoscandia were calculated by the method of least squares for three cases with different magnitude ranges, namely, Case 1: $M = 2 - 5$, Case 2: $M = 2 - 6.5$ and Case 3: $M = 3 - 6.5$. The results are given in Table 1 and illustrated in Fig. 3.

Table 1. Coefficients of magnitude frequency relations $\log N = a + b(8 - M)$ for the sub-zones of Fennoscandia.

Case	Region	Coefficients with standard errors	
		a	b
1	Vestlandet	-0.45 ± 0.12	0.52 ± 0.03
	Nordlandet	-1.13 ± 0.01	0.57 ± 0.00
	Oslo-Väner	-0.72 ± 0.10	0.55 ± 0.02
	Baltic	-0.82 ± 0.14	0.54 ± 0.03
	Karelia	-0.97 ± 0.28	0.51 ± 0.06
2	Vestlandet	-0.66 ± 0.12	0.56 ± 0.03
	Nordlandet	-0.67 ± 0.23	0.47 ± 0.06
	Oslo-Väner	-0.61 ± 0.02	0.60 ± 0.00
	Baltic	-1.15 ± 0.54	0.61 ± 0.04
	Karelia	-0.72 ± 0.55	0.46 ± 0.04
3	Vestlandet	-0.71 ± 0.17	0.58 ± 0.05
	Nordlandet	-0.47 ± 0.34	0.41 ± 0.09
	Oslo-Väner	—	—
	Baltic	-1.34 ± 0.15	0.67 ± 0.04
	Karelia	-0.73 ± 0.31	0.46 ± 0.09

6. *Statistical significance test of the difference between the coefficients* b *for the sub-zones of Fennoscandia*

In order to test the statistical significance of the difference between the coefficients b in the magnitude frequency relations $\log N = a + b$ $(8 - M)$ for different earthquake groups, the method derived to test the difference between regression coefficients, making use of »Student's t-distribution«, can be applied (FISCHER [3], TOKEI-KAGAKU KENKYU-KAI [12]).

When the regression formula takes the form

$$y = a + b(x - \bar{x}) ,$$

the Student's t for the difference of the b's from samples of different sizes N and N' is expressed by

$$t = \frac{b - b'}{\{s^2/\sum_{k=1}^{N} (x_k - \bar{x})^2 + s^2/\sum_{k=1}^{N'} (x'_k - \bar{x}')^2\}^{1/2}} ,$$

where

$$s^2 = \frac{1}{n} \{\sum_{k=1}^{N} (y_k - [a + b(x_k - \bar{x})])^2 + \sum_{k=1}^{N'} (y'_k - [a' + b'(x'_k - \bar{x}')])^2\} ,$$

and

$$n = (N - 2) + (N' - 2) ,$$
$$= N + N' - 4 .$$

Thus we calculated the value of $t = t_0$ for the differences between the b's of all combinations of the sub-zones and found the probability values of $|t| > t_0$ in the table of t given in the text book (FISCHER [3], TOKEI-KAGAKU KENKYU-KAI [12]). The results are shown in Table 2.

Within the significance level of 1% no significant difference has been recognized for all combinations in the three cases. If we adopt the significance level of 5%, Karelia and Nordlandet, on the one hand, and Oslo-Väner and the Baltic, on the other hand, can be said to have significantly different values of b in Case 2. However, it seems difficult to find any geological explanation of the difference. Case 1, on the contrary, considerably strengthens the argument for the statistical uniformity of all the sub-divisions of Fennoscandia in the magnitude frequency behavior expressed by b values. The statistics including the larger magnitude shocks, $i.e.$ Cases 2 and 3, will be examined later with more ample data.

7. Magnitude frequency relation for the whole of Fennoscandia

As the statistical examination confirmed the uniformity of the sub-divisions of Fennoscandia, the author treated the whole of Fennoscandia as a unit and calculated, by the method of least squares, the

Table 2. Student's t value for the freedom n, and the Pr. ($|t| > t_0$), which means the significance level of the differences between the b's of the sub-zones of Fennoscandia. —— for 5% and ～ for 2% significant difference.

Case 1 / Case 2	Vestlandet	Nordlandet	Oslo-Väner	Baltic	Karelia
Vestlandet	·	t_0 =1.83 n =2 Pr.=0.2	t_0 =0.80 n =2 Pr.=0.5	t_0 =0.50 n =2 Pr.=0.65	t_0 =0.15 n =2 Pr.=0.95
Nordlandet	t_0 =2.28 n =4 Pr.=0.08		t_0 =0.77 n =2 Pr.=0.5	t_0 =1.01 n =2 Pr.=0.4	t_0 =0.98 n =2 Pr.=0.4
Oslo-Väner	t_0 =2.50 n =3 Pr.=0.08	t_0 =3.91 n =3 Pr.=*0.027*		t_0 =0.26 n =2 Pr.=0.85	t_0 =0.60 n =2 Pr.=0.6
Baltic	t_0 =1.58 n =4 Pr.=0.18	t_0 =3.21 n =4 Pr.=*0.022*	t_0 =0.41 n =3 Pr.=0.7		t_0 =0.44 n =2 Pr.=0.7
Karelia	t_0 =3.13 n =4 Pr.=*0.036*	t_0 =0.23 n =4 Pr.=0.8	t_0 =5.58 n =3 Pr.=*0.011*	t_0 =3.95 n =4 Pr.=*0.016*	

Case 3	Vestlandet	Nordlandet	Oslo-Väner	Baltic	Karelia
Vestlandet		t_0 =1.62 n =2 Pr.=0.25	—	t_0 =1.43 n =2 Pr.=0.33	t_0 =1.24 n =2 Pr.=0.35
Nordlandet	—		—	t_0 =2.51 n =2 Pr.=0.12	t_0 =0.39 n =2 Pr.=0.75
Oslo-Väner	—	—		—	—
Baltic	—	—	—		t_0 =2.21 n =2 Pr.=0.15

magnitude frequency relation for it. This becomes: $\log N = (- 0.07 \pm 0.03) + (0.54 \pm 0.01)(8 - M)$, where N is the number of shocks during the period $1891 - 1950$ in all Fennoscandia excepting its peripheries.

Although this value of b, obtained after the critical examination of the data and method, is larger than BÅTH's value of 0.46, it still seems very small in comparison to the values of b for the other parts of the world. If the value of b has a universal constancy, as many seismologists have insisted, we must test the significance of the difference of this value from the so-called »theoretical» value of $b_0 = 0.9$, making use of Student's t test, as KOMURA [5, 6] applied the method in testing the variance of the coefficient m of the Ishimoto-Iida formula $n = n_0 e^{-mA}m$ for the frequency distribution of the recorded maximum amplitudes of earthquake motions. As the standard error of b is $s_b = \pm 0.01$,

$$t = \frac{b - b_0}{s_b} = \frac{0.9 - 0.54}{0.01} = 36$$

For the freedom of $n = N - 2 = 3 - 2 = 1$ of our case, the table of t gives $Pr(|t| > 36) = 0.02$. Accordingly, the difference $b - b_0$ can be said to be insignificant only with a probability of less than 2%. In other words, the b value 0.54 can be said to differ from the »theoretical» value of $b_0 = 0.9$ with a significance level of 2%. Thus the value 0.54 can also be said to differ significantly from the mean values of b for the circum-Pacific and Alpine regions, at least with the significance level of 5% or less. The difference from the block tectonic continental platform may be less definite and it will be a problem to be solved in future whether the shield region differs in seismicity from the rejuvenated continental platform or not.

REFERENCES

1. BÂTH, M., 1953: Seismicity of Fennoscandia and related problems. *Gerl. Beitr. zur Geophys.*, **63**, 173—208.
2. —»— 1956: An earthquake catalogue of Fennoscandia for the years 1891—1950. *Sveriges Geologiska Undersökning, Årsbok, Ser. C*, **545**, 1.
3. FISHER, R. A., 1948: *Statistical methods for research workers*, Tenth Edition, Oliver and Boyd, London, 140—141.
4. GUTENBERG, B. and C. F. RICHTER, 1949: *Seismicity of the earth and related phenomena*. Princeton University Press, Princeton.
5. KOMURA, S. On the maximum amplitude index in the Ishimoto-Iida's statistical formula. *Zisin (Journ. Seism. Soc. Japan)*, Ser. II, **7**, 145—150.
6. —»— Some stochastic results of the maximum amplitude index in the Ishimoto-Iida's statistical formula (1). *Ibid.*, 194—195.
7. MIYAMURA, S., 1960: *Earthquake province and its bearing on geotectonics.* Read at the XII General Assembly IUGG in Helsinki.
8. —»— 1962: Magnitude frequency of earthquakes and its bearing on geotectonics. *Proc. Jap. Acad.*, **38**, 27—30.
9. RIZNICHENKO, YU. V., 1958: Ob izuchenii seismicheskogo rejima. *Izv. AN SSSR, Ser. geofiz.*, 1057—1074.
10. SAHLSTRÖM, K. E., 1930: A seismological map of Northern Europe, *Sveriges Geologiska Undersökning, Årsbok*, Ser. C, **364**, 1—8.
11. SUZUKI, Z., 1953, 1955, 1958, 1959: A statistical study on the occurrence of small earthquakes, I—IV. *Sci. Rep. Tôhoku Univ., Ser. V. Geophys.* 177—182 (1953), 105—118 (1955), 15—27 (1958), 10—54 (1959).
12. TOKEI-KAGAKU KENKYU-KAI, 1943: Tokei Suchi-Hyo I, *Kawa-ide Sho-bo*, 97. Tokyo,
13. TSUBOI, C., 1958: Seismic activities in and near Japan. *Contribution in Geophysics*, **1**, In honor of Beno Gutenberg, Pergamon Press, London.

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46. *E. Vesanen, E. Penttilä, M. T. Porkka* and *J. Riihimaa:* Progress Report, 1960. Seismological Station of the University of Helsinki. Helsinki 1961.
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53. *Esko Penttilä:* Maan kuoren seismolcgisesta rakennetutkimuksesta Suomessa. Helsinki 1962.